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FACULTY OF MECHANICAL ENGINEERING

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„Conference on Mechanical Engineering Technologies and Applications“

PROCEEDINGS

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East Sarajevo, RS, B&H

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VARIANCES IN BUILDING ENERGY CONSUMPTION – INFLUENCE OF DOMESTIC HOT WATER SYSTEM PARAMETERS

Danijela Nikolić [1], Jasmina Skerlić [2], Vanja Šušteršič[3], Ana Radojević[4], Natalija Aleksić[5]

Abstract: Domestic hot water system (DHW) accounts a great amount of energy consumption in residential buildings. As buildings are large energy consumers, it is very important to implement all measures for reducing total energy consumption and to increase building energy efficiency. By using a system with solar collectors for water heating, significant savings in electricity consumption for domestic water heating can be achieved. In this study it is analyzed final energy consumption in a building with solar water heating system. Investigated building, located in the city of Kragujevac, is simulated in EnergyPlus software. Building design was carried out with Open Studio plug-in in Google SketchUp, and it had electric heating system and system of solar collectors for water heating. The researches were conducted on the impact of different hot water temperature and different hot water consumption to the amount of generated thermal energy in the solar system, as to the total energy consumption. At the end, the economic analysis of modeled solar system was carried out.

Key words: building; solar collector; water heating; simulation; energy saving

1 INTRODUCTION

In the past two decades, buildings are recognized as great energy consumers. Serbia has about 400 000 energy inefficient buildings, so energy consumption in buildings in Serbia is at the level of 50 % [1, 2]. These buildings have no thermal insulation and their heating energy demands are very high. That is the main reason for great energy consumption in Serbian building sector. At the other side, the exploitation conditions of the building also have a large rate in total energy consumption, where the large consumers are domestic hot water system, cooling system and inefficient electric appliances. Reducing of building energy consumption can be achieved by construction

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of energy efficient buildings, by using high efficient electric appliances and, which is the most important, by using the systems of renewable energy, which can generate the energy to partially or completely satisfying building energy needs. Energy efficient building has a lower total energy consumption and lower greenhouse gas emission because renewable energy sources do not pollute the environment [3].

Solar energy is the most promising source of renewable energy and represents the most reliable source of energy because it does not bring pollution, which is disproportionately large in the use of fossil fuels.

In Serbia, it is customary to use electricity for domestic hot water systems (SDHWS). As around 70% of electricity is produced by coal in Serbia, it is important to use solar energy for domestic water heating. In households, domestic hot water (DHW) is used for shower, tap, cloth-washing (machines), and dish-washing (machines) [4]. If this water is heated by electricity which is generated by coal burning, then the high amount of CO_2 is emitted into the atmosphere. By replacing electricity with solar thermal energy for water heating in households, the high reduction in CO_2 emission and reduction of building total energy consumption can be achieving. In renewable energy field, SDHWS have arisen a great research interest [5, 6]. To use SDHWS with the greatest benefit, SDHWS must have adequate design, installation, and operation.

This paper represents investigations of influence of different paramaters in SDHWS on total energy consumption in family building, Figure 1. The investigated buildings were located in Kragujevac, Serbia. The building is designed with solar collectors installed on the roof. Electricity in the building is used for heating, lighting, electric equipment and domestic water heating. Solar collectors generate heat energy which is used for domestic water heating. The rest of the energy needs are purchased from the electricity distribution system. Family building was designed in Google SketchUp with Open Studio plug inn, while data on energy consumption were obtained based on simulations performed in EnergyPlus software. Parameters such as monthly hot water consumption and hot water temperature in solar system are varied in order to obtain the largest generated heating energy for domestic water heating in the modeled building. At the end of investigation, an economic analysis is provided.

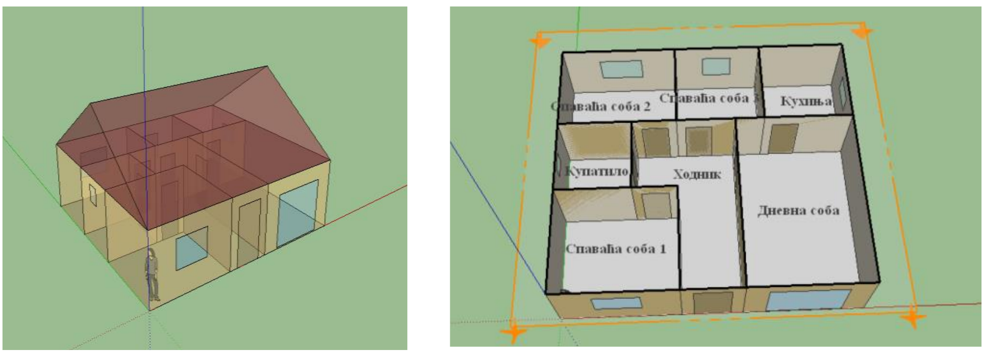

Figure 1. *Modeled building*

2 ENERGYPLUS MODEL OF SDHWS

EnergyPlus software has own model for domestic water heating with solar collectors. The SDHWS heats DHW by using solar and electric energy. The DHW is used as water for sink, bath, shower, dish washing and cloth washing. The SDHWS is schematically shown in Figure 2 in EnergyPlus environment. The SDHWS consists of the following main elements explained separately in the text below: the solar collector, storage water tank, instantaneous water heater, tempering valve, and temperature controls [7]. These elements are located in two inner loops of the SDHWS: the solar loop and the use loop. The solar loop is a loop through the solar collector.

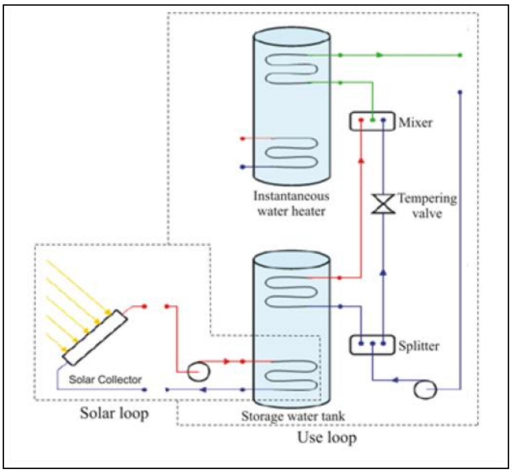

Figure 2. *Schematics of SDHWS for heating of DHW (adapted from [8])*

The use loop is a loop for DHW consumption. The solar loop consists of the solar collector, water pump, and spiral pipe heat exchanger (inside the hot water storage tank). The use loop consists of the splitter, storage water tank, instantaneous water heater, tempering valve, and mixer. Inside the solar loop, the solar collector captures solar energy. This energy heats water that flows through the solar collector. Furthermore, the hot water heats DHW in the storage water tank. In the use loop, the cold water reaches the splitter. From the splitter, the domestic water may go to the storage water tank or to the tempering valve. In the storage water tank, DW is heated from the solar loop via the spiral pipe heat exchanger. From the storage water tank, the hot water goes to the instantaneous water heater where can be additionally heated. Then the hot water from the instantaneous water heater and the cold water from the tempering valve go to the mixer and after that as DHW to the consumers. The water temperature in the storage tank may be higher or lower than the needed DHW temperature. The investigated solar collector is of flat plate type [7].

Water thermal tanks are devices for storing thermal energy in water from the SDHWS. The input object of EnergyPlus (WaterHeater:Mixed) provides a model that simulates a storage water tank (well-mixed water tank), and also instantaneous water tank (tank-less water heater). The tempering valve acts to divert flow through the branch it is on in order to adjust the temperature at the outlet of the mixer.

To control use of this installation, several temperatures will be supported in the solar loop by using the control equipment inside this installation. The maximum flow rate is 0.00006 m^3/s. Main parameters of solar heating installation for water loop through the solar collector are the following: Loop temperature ($T_L=70^0C$), High temperature turn off in solar loop (70^0C), Temperature difference on limit (differential thermostat) (10^0C), Temperature difference off limit (differential thermostat) (2^0C). In the use loop: Main supported temperatures are the hot water setpoint temperature (variable temperature in this investigation: $T_H=50\ ^0C$, $60\ ^0C$, $70\ ^0C$) and the maximum temperature limit for storage tank ($82.2\ ^0C$) [7].

Hot Water Consumption: This installation generates four different types of hot water: for tap, shower, dish-washer, and cloth-washer. Regarding its application, the water would be heated to two temperatures: 43.3 ^{0}C (tap and shower with the maximum flow rate of 0.0000945 m^3/s) and 50 ^{0}C (or 60 ^{0}C and 70 ^{0}C in different cases) for dish and clothes washer with the maximum flow rate of 0.000063 m^3/s. The cloth washer operates only on Sunday.

3 ENERGY CONSUMPTION IN ANALYZED BUILDING

Total energy consumption E_p in a building is related to the electricity. Electricity in a building is consumed for heating (eh), lighting (el), domestic hot water (DHW) and appliances (eq).

$$E_p = E_{ac} + E_{eh} + E_{eq} + E_{el} \quad (1)$$

where:

- E_{eh} - electricity consumption of the electric heating,
- E_{el} - electricity consumption for lighting,
- E_{el} - electricity consumption for DHW system and
- E_{eq} - electricity consumption for the appliances - electric equipment.

Primary energy consumption E_{prim} of the building is

$$E_{prim} = p_{EL} E_p \quad (2)$$

where p_{EL}=3.04 stands for the primary conversion multiplier for electricity [1].

4 RESULTS AND ANALYSIS

The aim of this investigation is to show the influence of parameters such as monthly hot water consumption and hot water temperature in solar system to generated heating energy in the modeled building. Figure 3 shows the distribution of annual building energy (electricity) consumption for the case of building with thermal insulation thickness of 0.15 m, without the solar collector (left) and, for the reference case (right) - building with a solar collector installed on the south oriented part of the roof. The building was simulated when the heating system was operating from October 15 to April 15 of the following year, which is a common practice in Serbia.

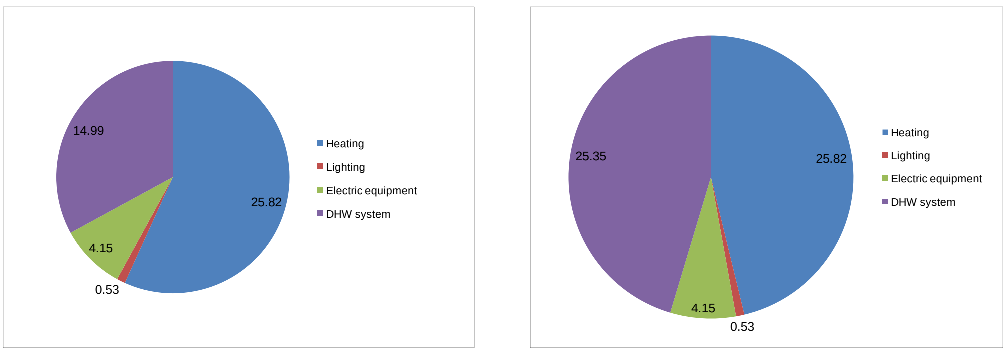

Figure 3. *Schematics of building energy consumption for the building with SDHWS (left) and reference building without SDHWS (right)*

In the reference case, this building has monthly hot water consumption of 11.5 m^3/s, water temperature of 60ºC, and collector surface of 4 m^2.

This consumption is adequate for the consumption of hot water by the average four-member family for one month (total average monthly consumption of water per household member is 5 m^3/s). Cases with monthly hot water consumption of 8 m^3/s, 15 m^3/s and 20 m^3/s were analyzed. The results of the energy consumption obtained by simulation as well as the generated energy by the solar system are given in Table 1.

Table 1. *Annual electricity consumption and generated energy (GJ) in the building for different values of monthly hot water consumption*

Energy consumption	8 m^3/s	11.5 m^3/s	15 m^3/s	20 m^3/s
Heating	25.82	25.82	25.82	25.82
Lighting	0.53	0.53	0.53	0.53
Electric equipment	4.13	4.15	4.18	4.2
DHW system	9.92	14.99	20.40	28.72
Total energy consumption	40.4	45.49	50.93	59.27
Generated energy	8.76	10.36	11.68	13.17

Figure 4 shows the electricity used for water heating, compared to the thermal energy generated by the solar collector and the consumed electricity in the case of building without a solar collector.

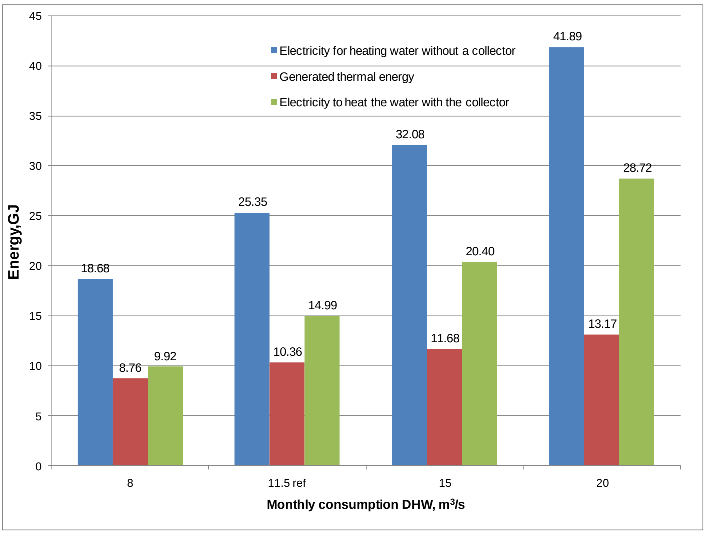

Figure 4. *Generated thermal energy and water heating energy before and after the installation of the solar collector*

During the energy behavior analysis of the building, temperature of hot water was also varied. This temperature refers to the temperature at the top of the boiler, since the temperature is at the bottom of the water heater is limited to 10ºC less. Table 2 shows the obtained results.

Table 2. *Annual electricity consumption (GJ) for different hot water temperatures*

Energy consumption	50ºC	60ºC ref.	70ºC
Heating	25.82	25.82	25.82
Lighting	0.53	0.53	0.53
Electric equipment	4.17	4.15	4.14
DHW system	13.22	14.99	16.45
Total energy consumption	43.74	45.49	46.94
Generated energy	11.43	10.36	9.56

Figure 5 shows the electricity used for water heating, compared to the generated heat by the solar collector and electricity that would be wasted without a solar collector.

Best cases - It was determined that the minimum consumption of electricity for water heating is for amount of 8 m^3. The lowest energy consumption for water heating is obtained at a temperature of 50 °C. The average area of a commercial solar collector is 2 m^2 and two collectors are sufficient fr water heating in a smaller household [10]. T By simulating these parameters, the optimal results are obtained (Table 3). In the best case, the generated energy is greater than the electricity used for water heating, which is not the case for the reference building (10.36 GJ <14.99 GJ).

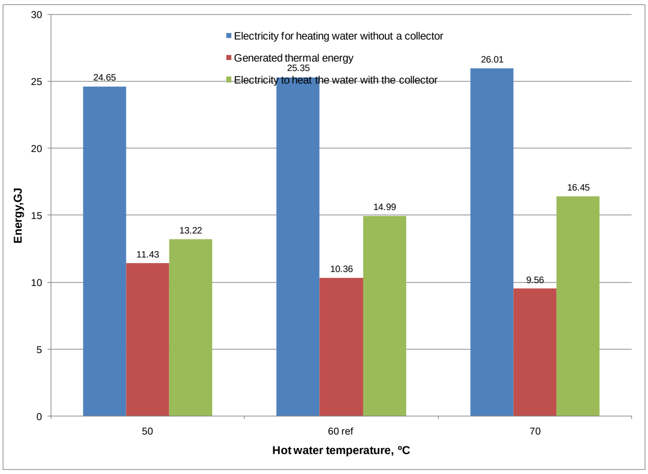

Figure 5. *Energy for water heating, before and after installation of the solar collector and generated thermal energy*

Table 3. Optimal case - energy consumption and generated thermal energy

Energy consumption	8 m^3/s, 50ºC, 4 m^2
Heating	25.82
Lighting	0.53
Electric equipment	4.15
DHW system	8.30
Total energy consumption	38.8
Generated energy	8.76

In the total consumption of electricity, the energy required for the preparation of hot water is 21.40%, and for the reference case, it is 32.95%. It is concluded that it is possible to obtain a more favorable case for another 11.55% less electricity consumed for heating water than the reference case. Electricity for heating water is reduced by installing a solar collector on the house. In addition to the installation itself, savings can be achieved by lower monthly consumption of hot water, lower temperature and the appropriate collector surface, which proves the fact that in an optimal case, the consumption was reduced by 6.69 GJ compared to reference case, i.e. by 43.9%.

Based on the *economic analysis* of the optimal solar system, it is concluded that the annual generated thermal energy is 8.76 GJ, that is 2434 kWh (or 2,434 MWh) of energy. This would mean that around 6.7 kWh is generated daily. If the annual generated energy is multiplied by the price of 8.9 euro cents per kWh, annual savings of 217 euros or 25718.84 dinars will be obtained. The average cost of a solar installation is €1500, so, the conclusion is that it takes just under 7 years for the initial investment to pay off.

5 CONCLUSION

Solar energy can be directly used as the largest renewable source for domestic hot water heating. The house for a family of four members in Kragujevac is analyzed in this paper. The usage of solar collectors can result in significant energy savings for the heating of sanitary water and thus significant savings in energy consumption.

Simulations were conducted for the parameters: monthly hot water consumption and hot water temperature. It is concluded that the most favorable case is when the monthly hot water consumption is 8 m^3/s, temperature water 50ºC and collector surface of 4 m^2. Then the annual energy consumption for water heating is 2305.5 kWh, which is a 44.7% saving compared to the reference case. In the most favorable case, with an annual generated thermal energy of 2434 kWh, the return on investment is around 7 years.

In addition to saving energy and money, the environmental influence of renewables is important. Solar energy is pure energy. In our country, this type of energy use is not sufficiently developed, so it is necessary to intensify activities in the field of energy efficiency and environmental protection.

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